

# **CO<sub>2</sub>/O<sub>2</sub> (Oxyfuel) Combustion for Coal-Fired Power Generation with CO<sub>2</sub> Capture – Opportunities and Challenges**

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# The Vattenfall Group

- Vattenfall sells about 180 TWh electricity, whereof about 160 TWh is produced by ourselves
  - The main part is produced by hydropower, nuclear power, coal.
  - A smaller part is produced by natural gas, biofuels and wind power
  - About 17 TWh is produced in combined heat and power plants
- Vattenfall also sell about 37 TWh heat where all is produced by ourselves
  - The main part is produced by biofuels, coal and gas in cogeneration plants
- Vattenfall emits almost 80 million tons of CO<sub>2</sub> per annum

# Options to reduce CO<sub>2</sub>

- The options available to reduce the CO<sub>2</sub> emissions from fossil fuelled plants are:
  - To increase the efficiency. Example: The renewal of the power plants in the new countries in Germany reduced the CO<sub>2</sub> emissions by 40% adjusted for the same energy production.
  - Change to another fuel with less carbon, or to biofuels which is renewable.
  - Capture and permanent storage of CO<sub>2</sub>

Vattenfall works with all options

# Power Plant Lippendorf



# The EU emission trading system

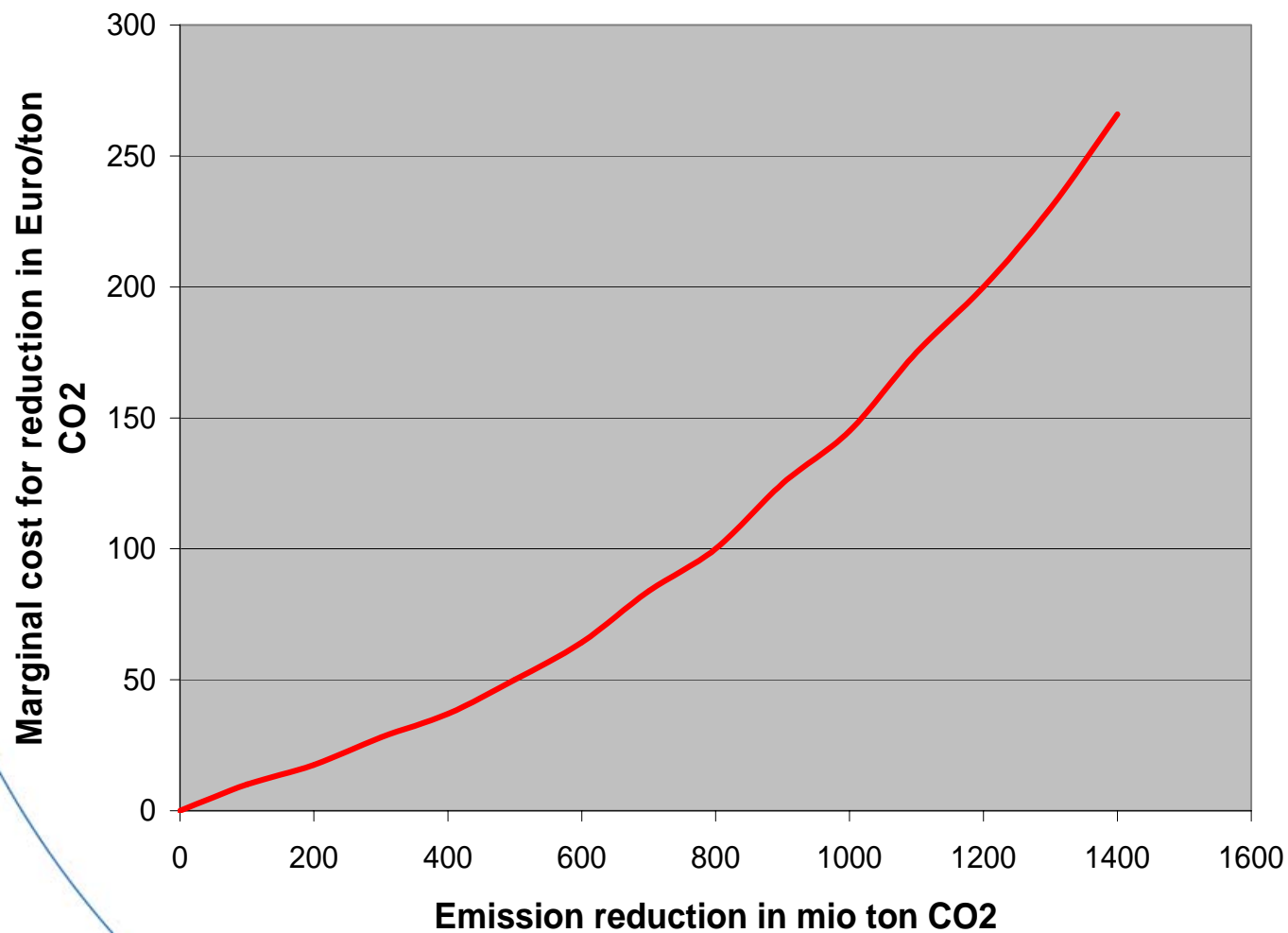
The long term price of the allowances will be set by reduction requirements and the costs of physical reduction

As emission allowances become scarce they will have an increasing value

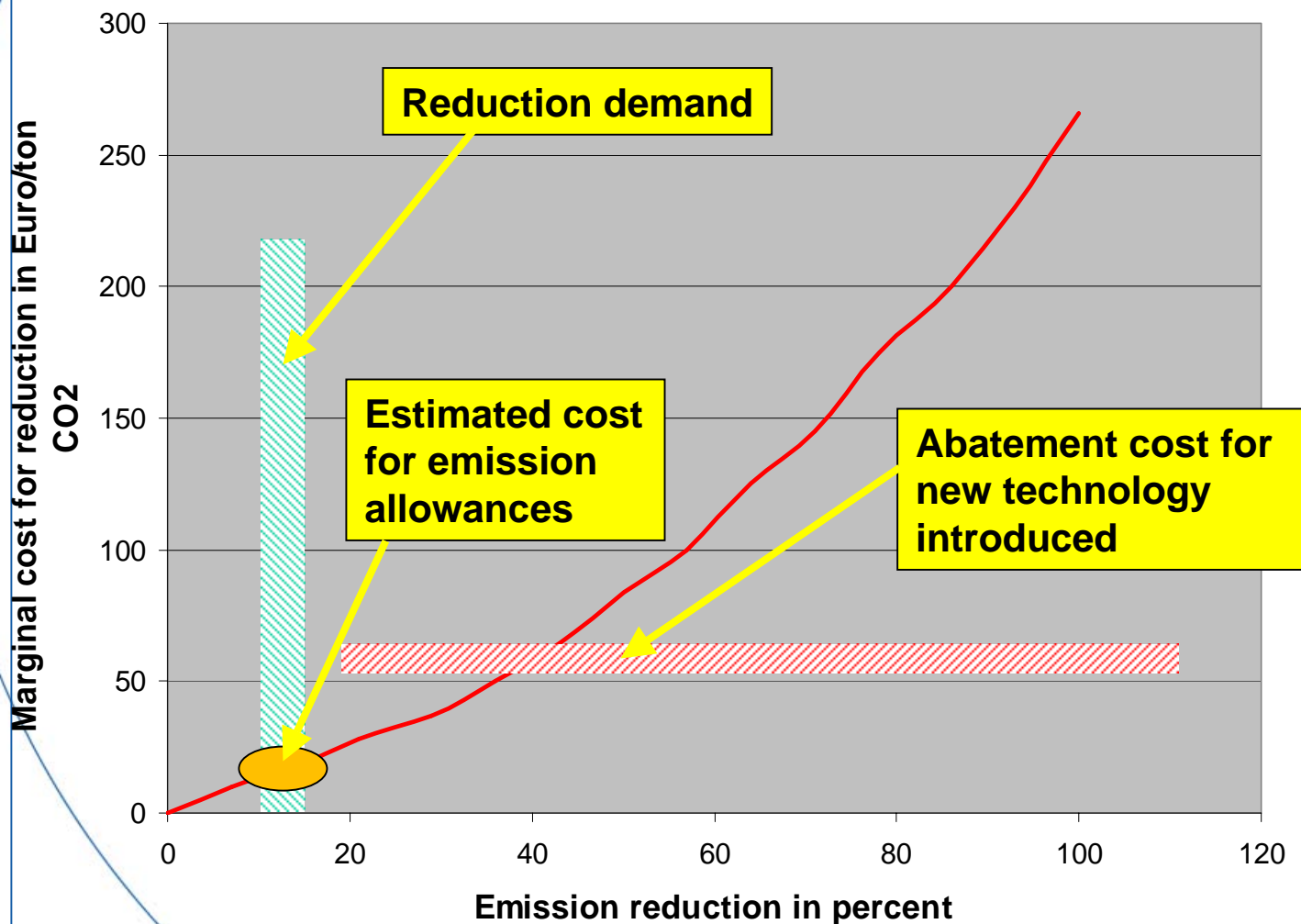
The cost for allowances will be added as a direct marginal production cost and therefore increase the spot price of electricity

## Marginal cost vs. Reduction of CO<sub>2</sub> emissions in EUR/ton CO<sub>2</sub>

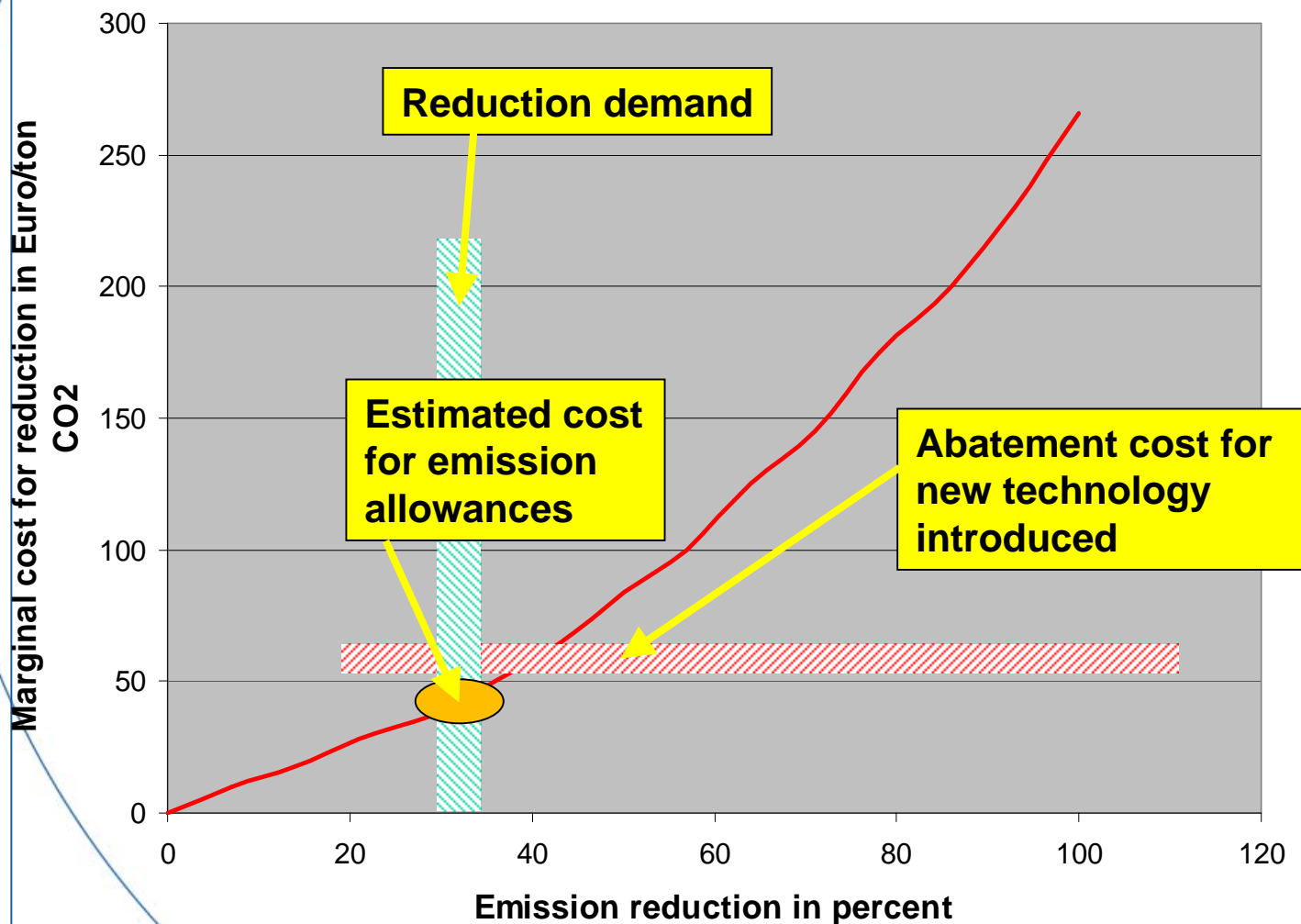
Source: ECOFYS Economic evaluation of sectorial reduction objectives for climate change



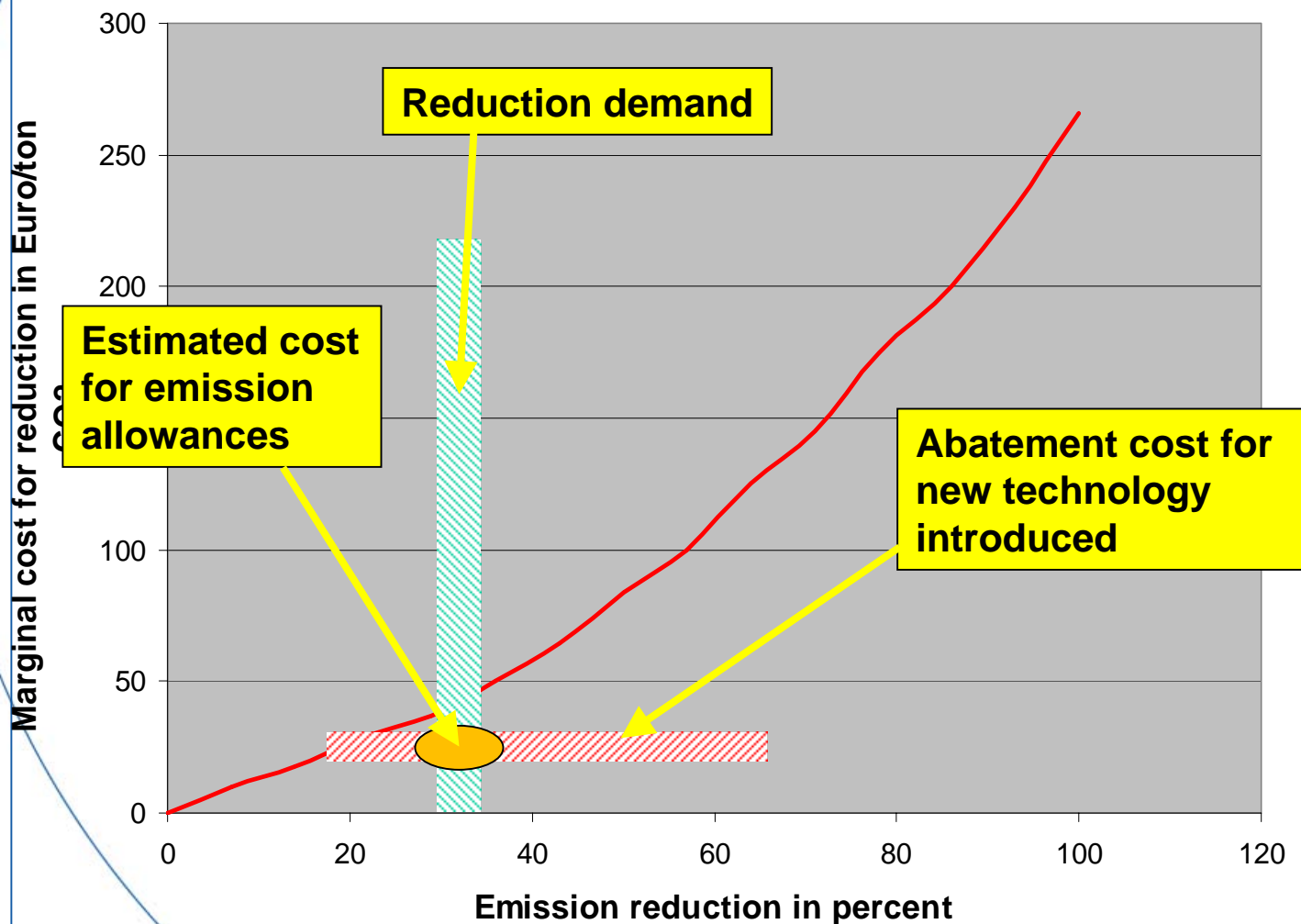
## Marginal cost vs. Reduction of CO<sub>2</sub> emissions in EUR/ton CO<sub>2</sub>



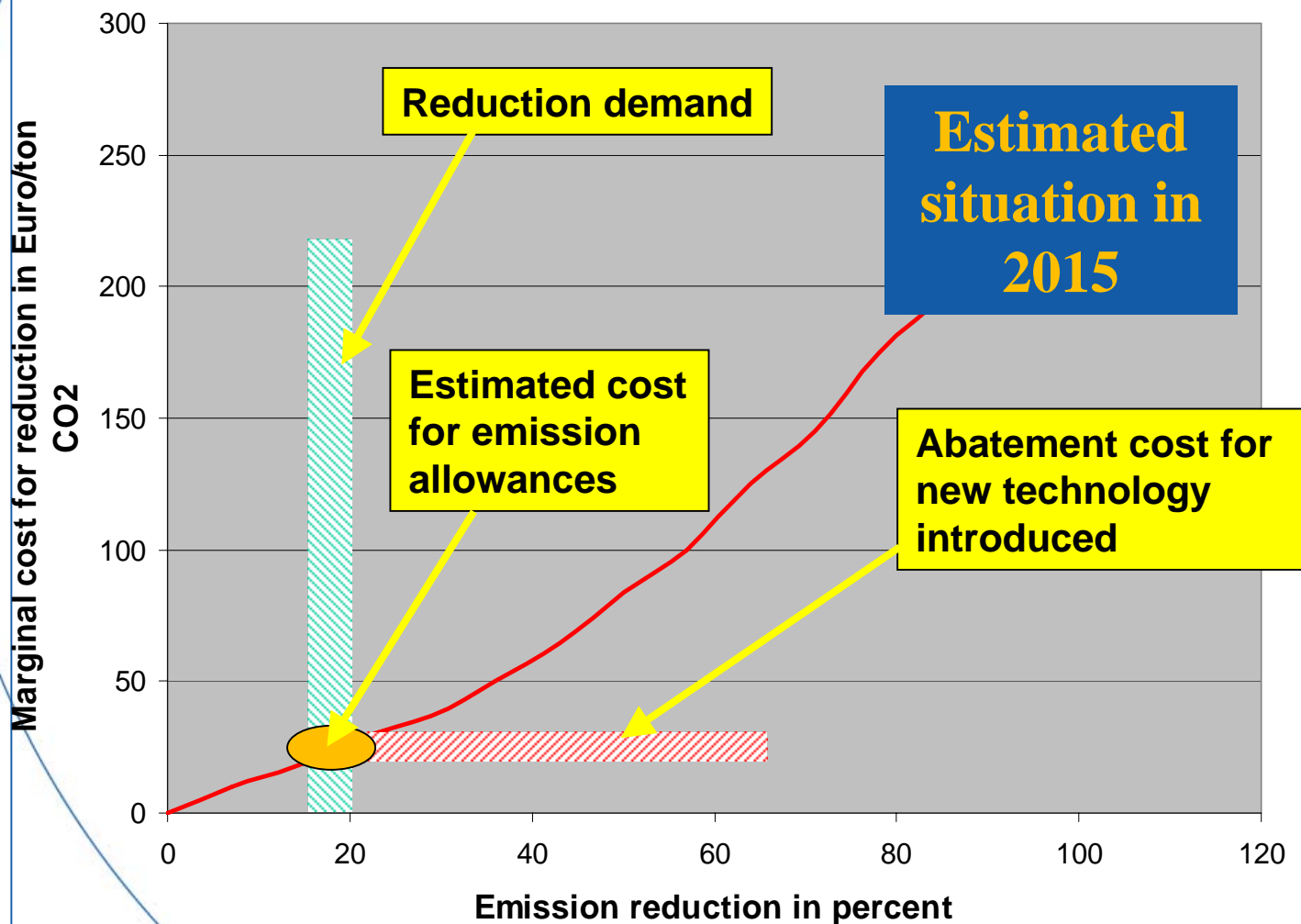
## Marginal cost vs. Reduction of CO<sub>2</sub> emissions in EUR/ton CO<sub>2</sub>



## Marginal cost vs. Reduction of CO<sub>2</sub> emissions in EUR/ton CO<sub>2</sub>



## Marginal cost vs. Reduction of CO<sub>2</sub> emissions in EUR/ton CO<sub>2</sub>



# Analyses show that...

## by 2010 .....

- Costs for emission allowances will probably be around 10 EUR/ton of CO<sub>2</sub>

## but in 2015....

- If the trading system prevails
- When new technology for fossil fuels with near zero emissions, can play a significant role
- The cost for emission allowances will increase to 20 EUR/ton of CO<sub>2</sub> or higher depending on reduction demand.



This is the target to be met by new "zero emission" technology

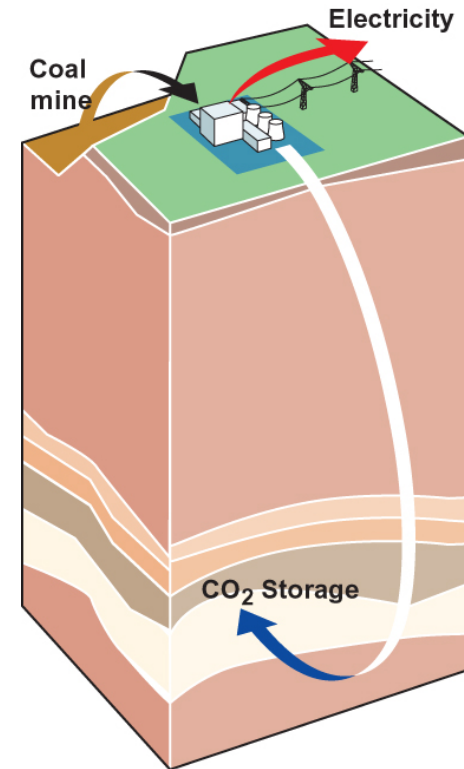
# The CO<sub>2</sub>-free Power Plant Project

## Objective:

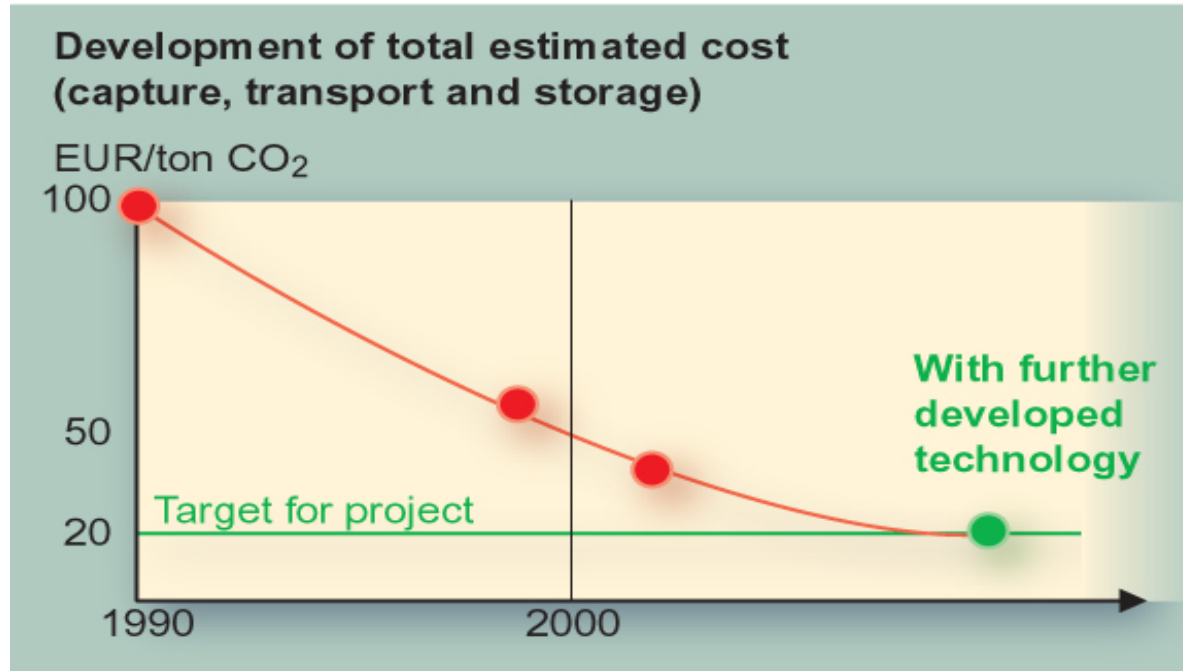
Secure competitive future energy supply and reduce greenhouse gas emissions

## Target:

Secure and feasible technologies for almost complete elimination of carbon dioxide emissions at cost effective levels

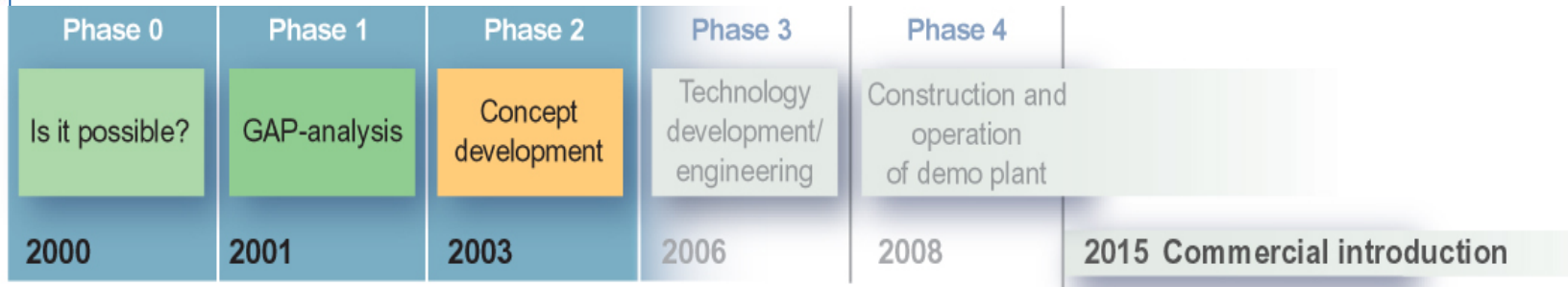


# Commercial concept in 2015



- Capture CO<sub>2</sub> from coal-fired power plant and store CO<sub>2</sub> deep underground
- Development target 20 €/ton stored CO<sub>2</sub>
- A 250 MW electricity demo plant latest 2010
- Develop a commercial concept until 2015

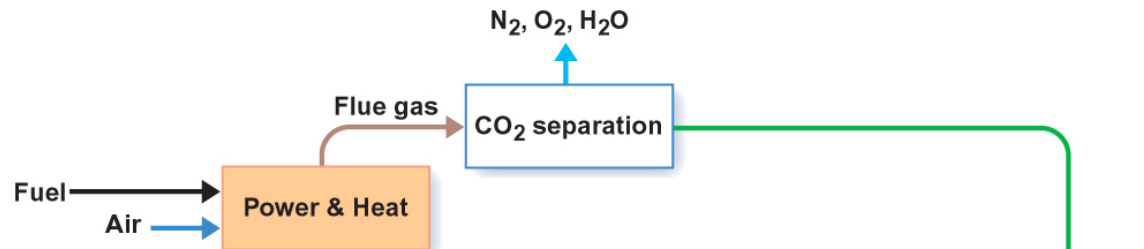
# 15 years of research and development



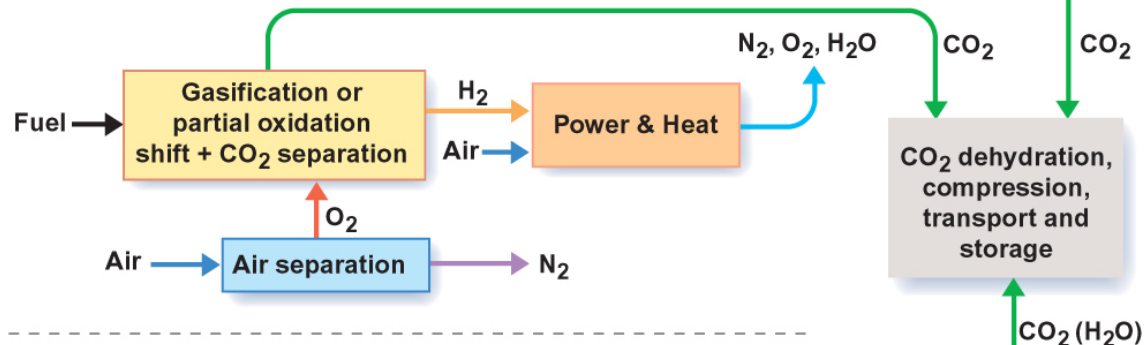
- Initial feasibility studies in 2001
- GAP analyses in 2002
- Concept development in 2003-2006
- A 250 MW electric demo-plant by latest 2010
- Commercial concept by 2015

# Three capture concepts

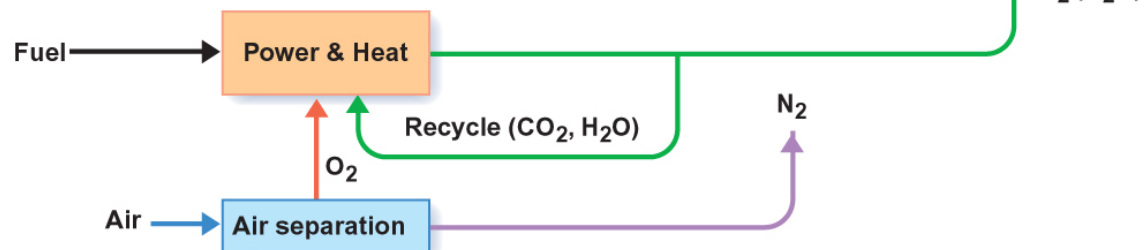
## Post-combustion capture



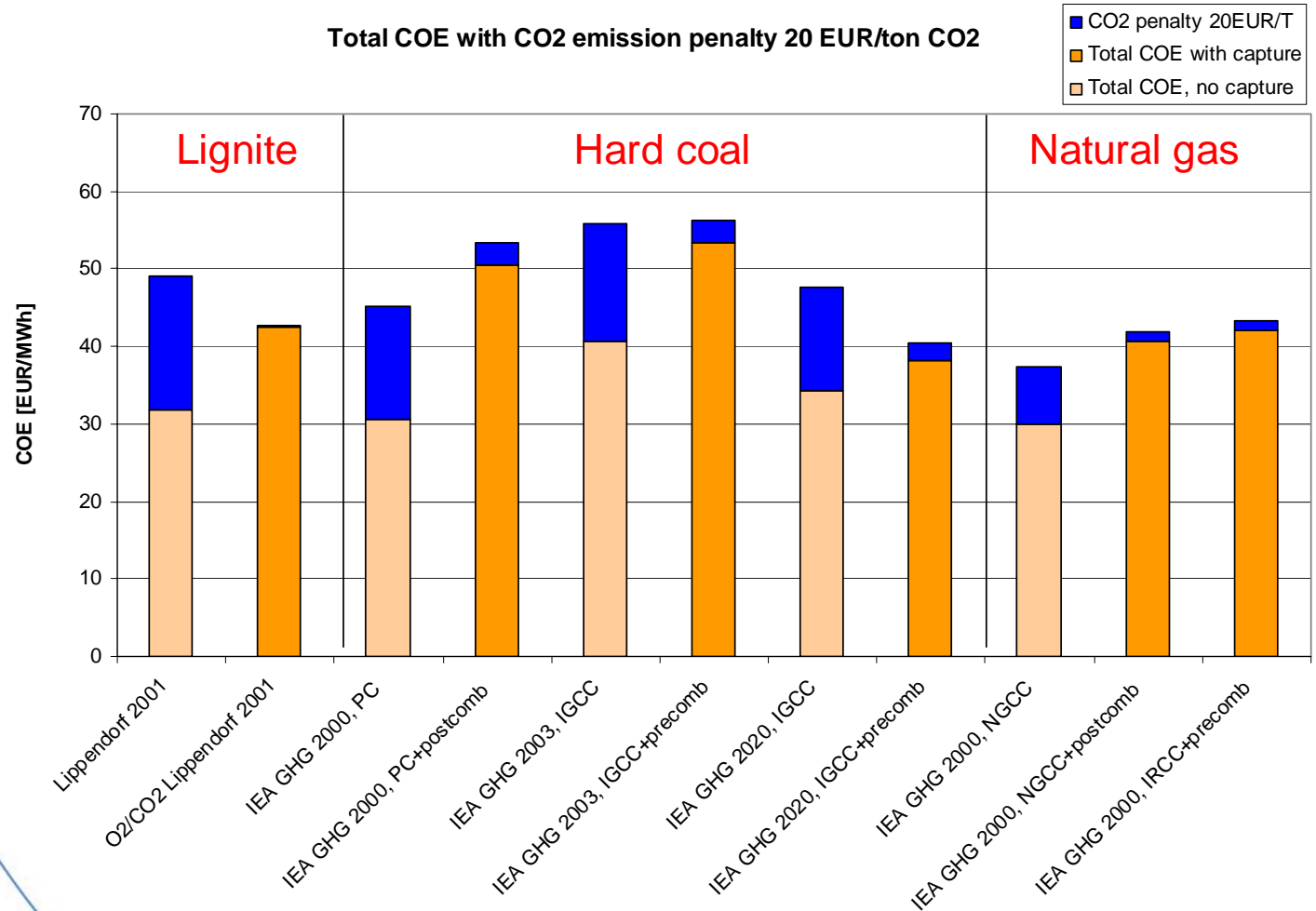
## Pre-combustion capture



## O<sub>2</sub>/CO<sub>2</sub> recycle (oxyfuel) combustion capture



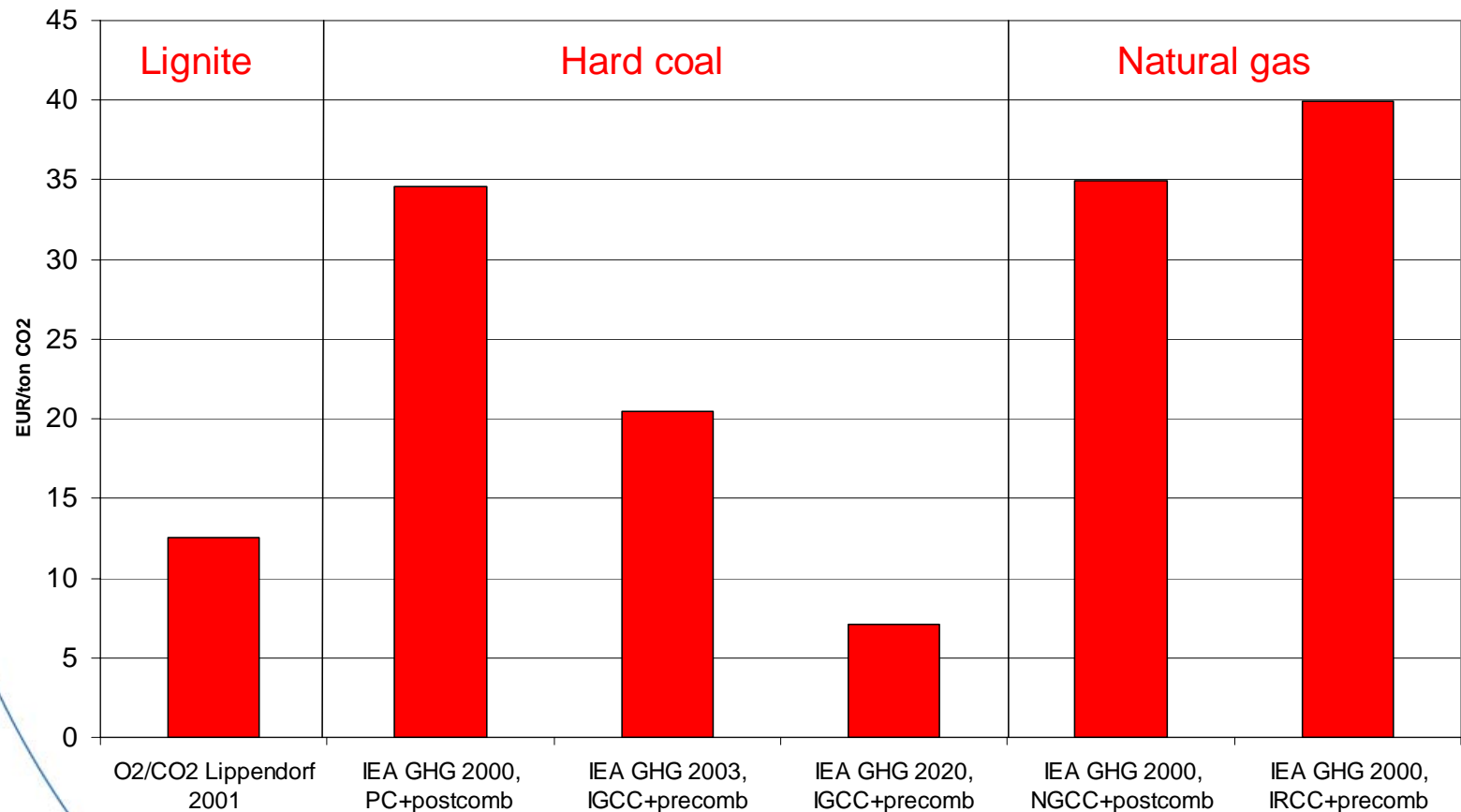
# COE with emission penalty 20 EUR/ton



Rate of return: 7%; Depreciation time 25 years; Operational time 7500 h/year

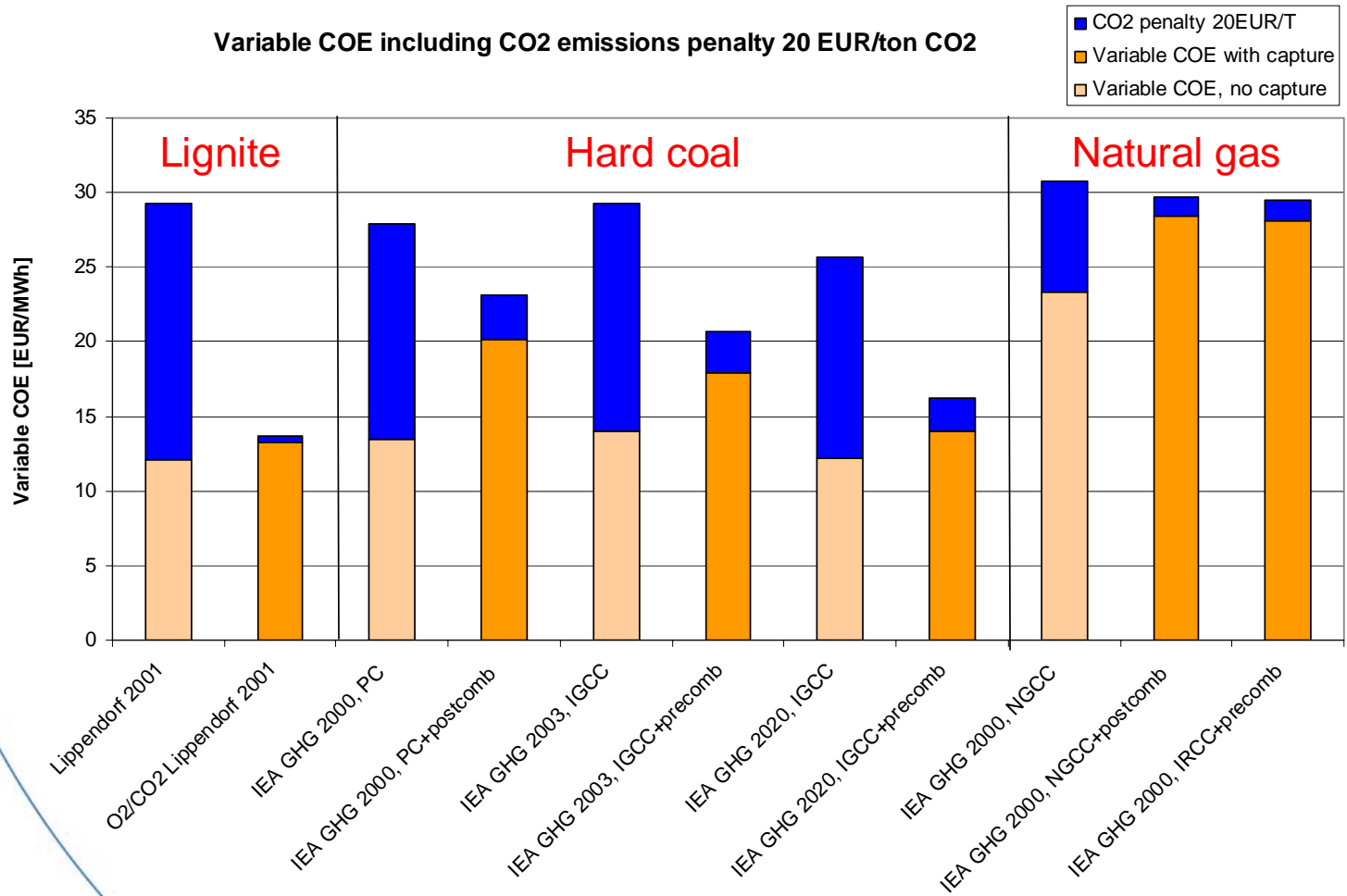
# CO<sub>2</sub> avoidance cost, capture

Transport and storage excluded

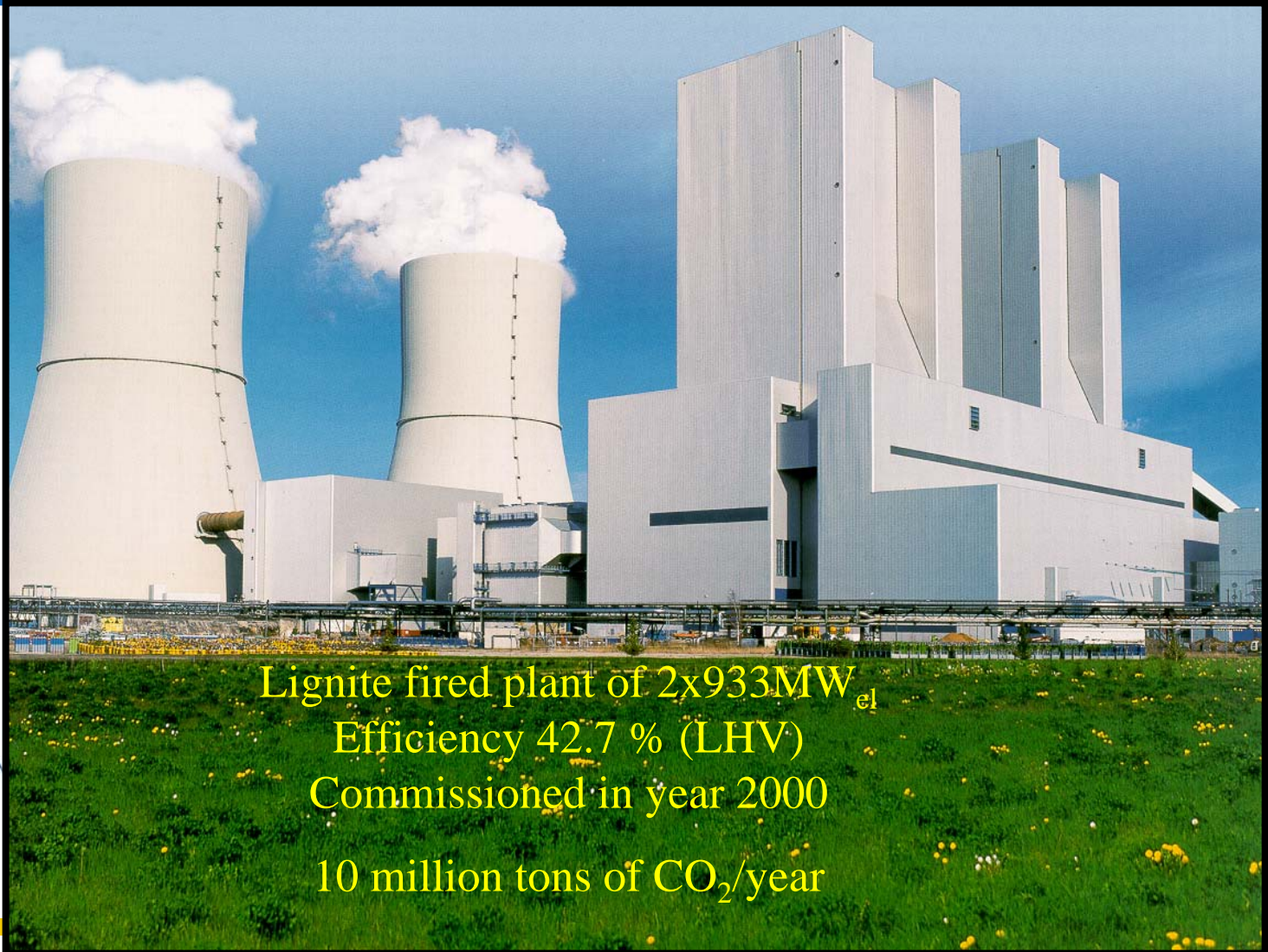


Rate of return: 7%; Depreciation time 25 years; Operational time 7500 h/year

# Variable COE with emission penalty



# The reference power plant Lippendorf



## CO<sub>2</sub> – Capture

### Evaluation of options

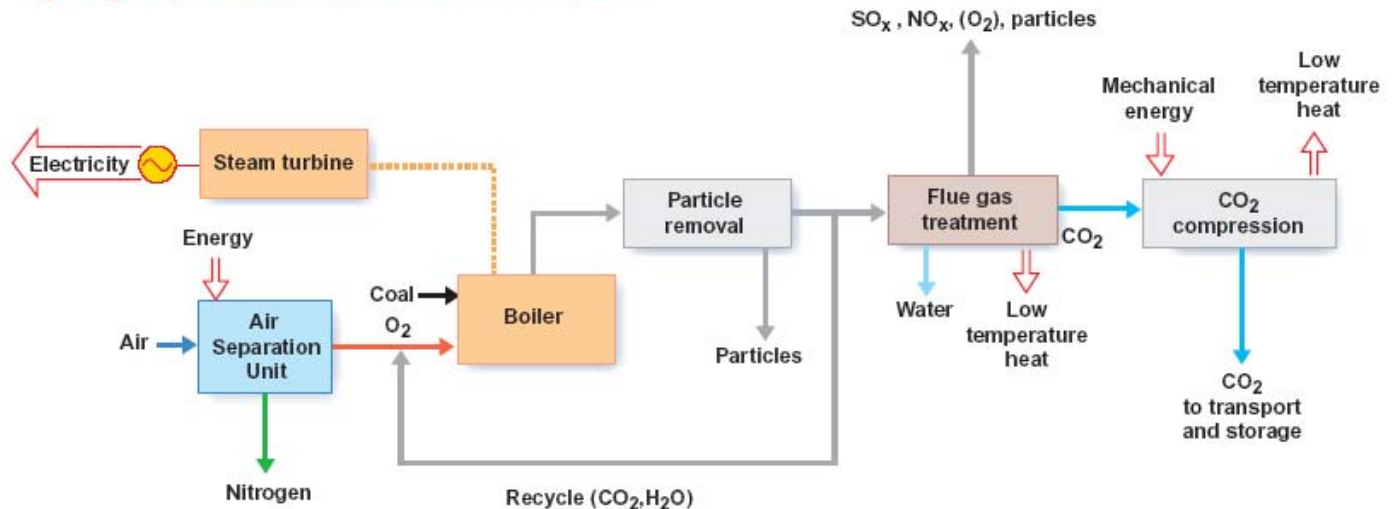
A preliminary evaluation of different options for CO<sub>2</sub> capture from coal fired plants has been made.

- Major conclusions are:
  - Of the three available technologies, IGCC, O<sub>2</sub>/CO<sub>2</sub> combustion and MEA absorption, the first two seems most attractive

Vattenfall will continue to study all three options, with emphasis on the two first, and most effort into O<sub>2</sub>/CO<sub>2</sub> combustion, due to that others work with the other two.

# The CO<sub>2</sub>/O<sub>2</sub> combustion principle

O<sub>2</sub>/CO<sub>2</sub> recycle (oxyfuel) combustion capture



Large energy penalty for O<sub>2</sub> production

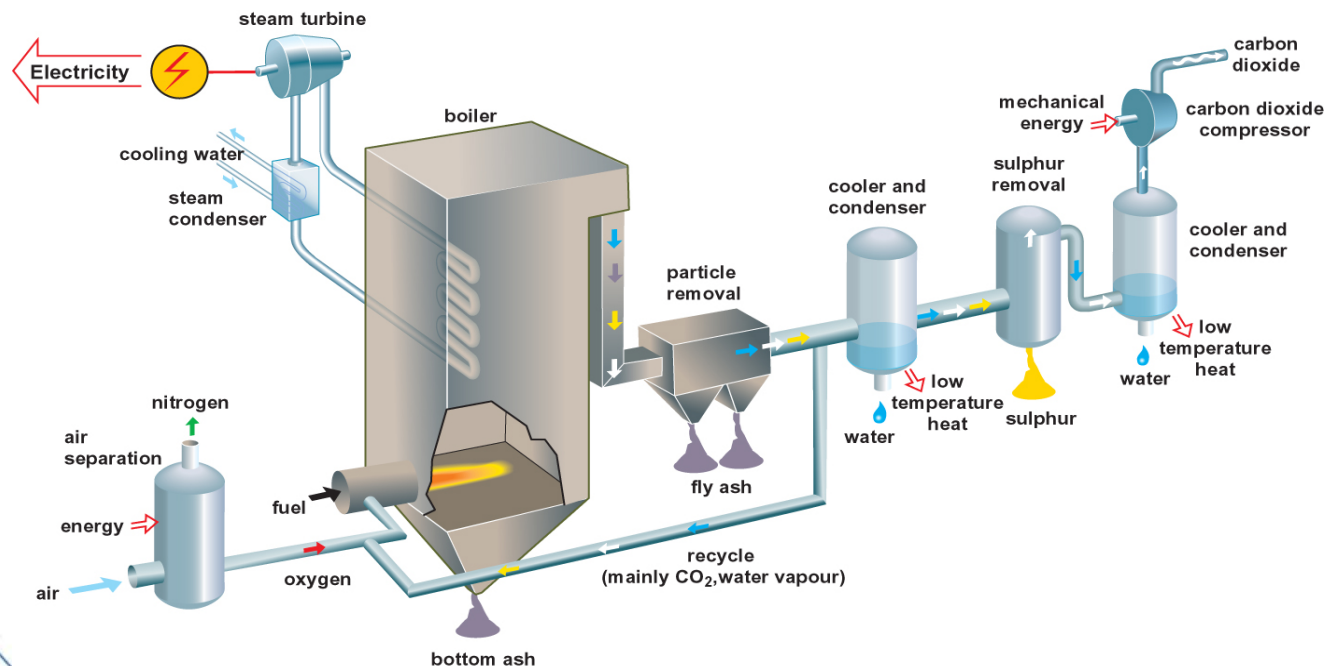
Large amount of waste heat, not only from steam condenser but also from flue gas condenser and CO<sub>2</sub> compression

# Opportunities with oxyfuel combustion

- Based on existing boiler and steam cycle technology
  - Can take advantage of ongoing development to increase efficiency of conventional power plants, e.g. AD700
- Co-capture of CO<sub>2</sub> and other pollutants gives a near zero emission power plant
  - Reduction in cost of flue gas treatment
- Next generation novel boiler designs
  - Compact PF boiler design through low recycle rate (higher oxygen concentration)
  - CFB gives opportunity to even lower recycle rate through use of solids for heat transfer

# Challenge 1: Boiler design

- Design of next generation oxyfuel boiler, combustion considerations
- Reduced recycle rate or complete removal of recycle
- Optimisation of combustion for reduced formation of  $\text{NO}_x$ , to eliminate catalytic reactors



## Challenge 2: Energy consumption of O<sub>2</sub> production

- Cryogenic air separation only currently available technology for large scale oxygen production; issues:
  - Scale-up
  - Optimal integration in power plant
  - Oxygen purity optimisation: where to remove the non-condensables?
- Emerging technologies?
  - High temperature oxygen separation with ceramic materials, e.g. oxygen transfer membranes:
    - Scale-up and cost?
    - Integration into power plant

## Challenge 3: CO<sub>2</sub> processing

- NO<sub>x</sub> control needed?
- Flue gas desulphurisation needed?
- Flue gas condensing
- Design of CO<sub>2</sub> compression train depending on CO<sub>2</sub> impurity level:
  - Removal of non-condensables
  - Dehydration?
  - Requirements on CO<sub>2</sub> purity from transport, storage environmental perspective is generally unexplored
  - Behaviour of CO<sub>2</sub> with impurities at high pressures (supercritical) is not well known (solubility etc.)

# CO<sub>2</sub>/O<sub>2</sub> combustion in the ENCAP project

**ENCAP - Integrated project within the EU-commission's 6<sup>th</sup> Framework programme, priority "Sustainable Energy Systems"**

- Development and verification of pre-combustion capture technologies
- The goal is to "cut lead time and improve cost for emerging pre-combustion capture technologies" (<20€/tonne CO<sub>2</sub> avoided at minimum 90% capture rate)

## **Objectives: CO<sub>2</sub>/O<sub>2</sub> boiler technologies**

- to **develop and validate** oxyfuel combustion based power plants concepts for bituminous coal and lignite for a greenfield power plant (both PC and CFB)
- To **provide a conceptual boiler design and suggest its integration** with a power generating plant to provide an economically competitive technology
- To examine special issues related to oxyfuel combustion in **laboratory and pilot scale** to be able to accommodate for those in the plant design and mitigate risk

**Participants: 28 European companies and organizations, as ALSTOM Power, Mitsui Babcock, Siemens, Air Liquide, Linde, BOC, Vattenfall, PPC, E2, RWE, U. Stuttgart, Chalmers, U. Ulster**

# ENCAP project partners

- Power companies
  - Energi E2, Public Power Corporation, RWE Rheinbraun, RWE Power, Vattenfall (project leader)
- Manufacturers
  - ALSTOM Boilers Power and Turbines, Mitsui Babcock, Siemens
- Technical gas companies
  - Air Liquide, BOC, Linde
- Gas and oil companies
  - Statoil
- Engineering companies
  - Lurgi, Uhde
- Research institutes
  - IFP, Sintef, DLR, ISFTA, TNO
- Universities
  - Chalmers UT, Imperial College, IST, NTNU, U Lund, U Ulster, U Paderton, U Stuttgart, U Twente

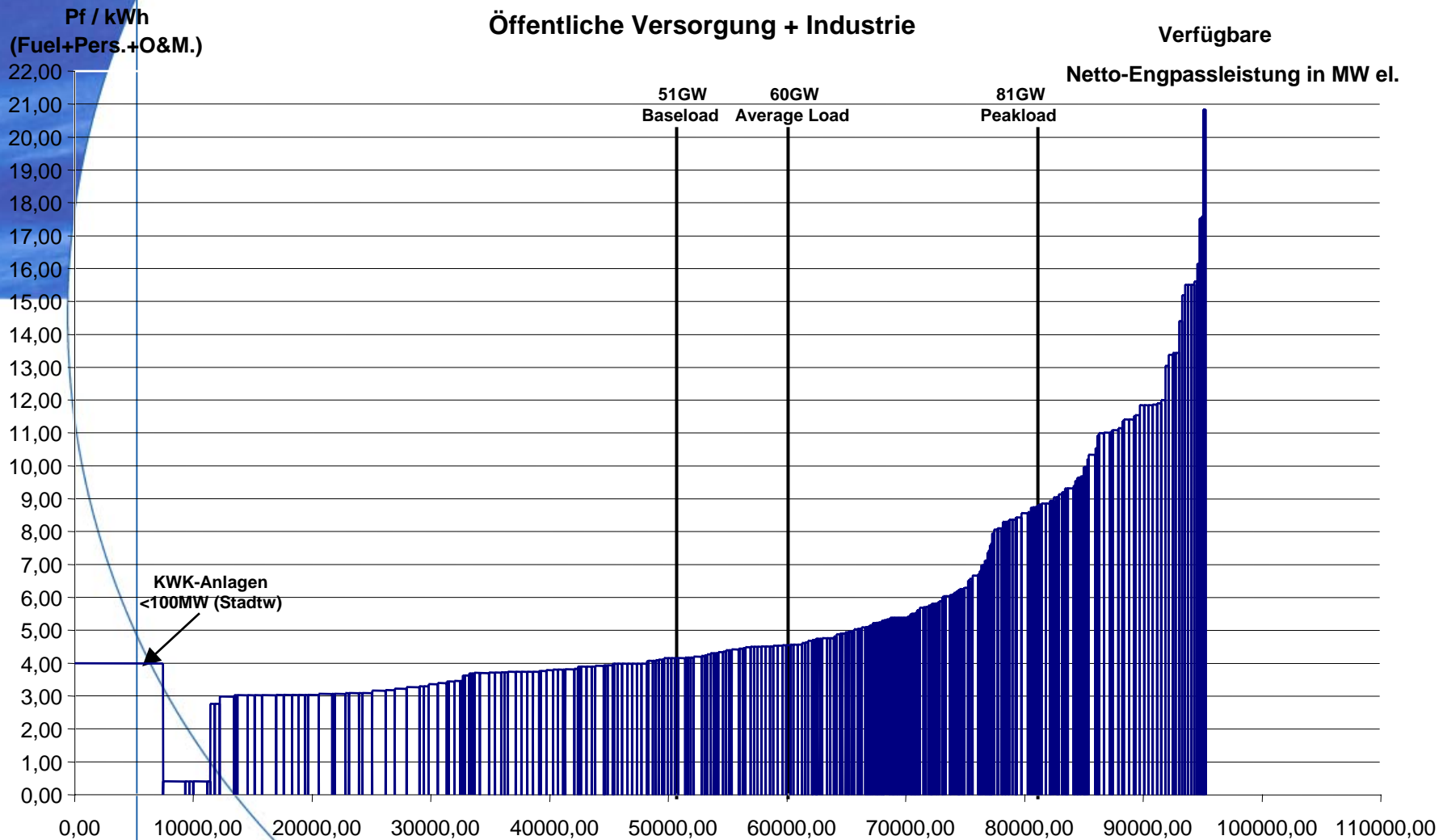
# Schwarze Pumpe power plant



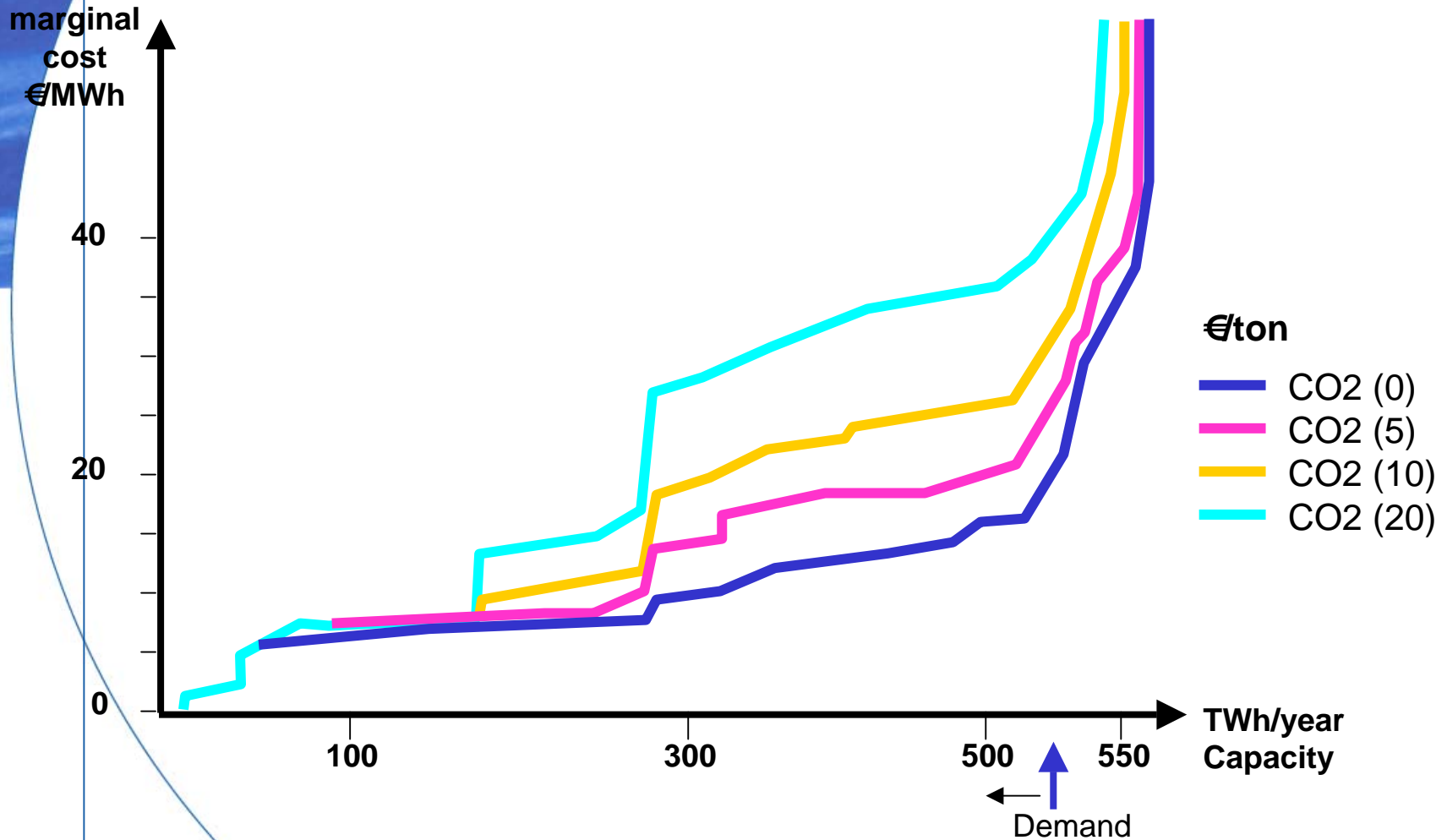
# Backup pictures

# SUPPLY CURVE GERMANY 2000

## Longterm variable costs



# Supply and Demand in Germany



# BoA Niederaußem



## Technical specifications:

• Net power output	965 MW
• Net efficiency	45.7 %
• Live steam pressure	260 bar
• Live steam temperature	580 °C
• Reheat steam temperature	600 °C
• Condenser pressure	< 35 mbar
• Flue gas temperature at FGD inlet	100 °C

## Project schedule:

Start of project:	01.07.1996
Start of licensing procedure:	21.03.1997
Granting of license:	12.11.1997
Start of site preparation :	12.12.1997
Start of construction:	03.08.1998
Commissioning:	August 2002.